Summary of RIKEN BNL workshop

P- and CP-odd effects in hot and dense matter

April 26-30, 2010

Talks online at: http://quark.phy.bnl.gov/~kharzeev/cpodd

Harmen Warringa, Goethe Universität, Frankfurt

Caveats

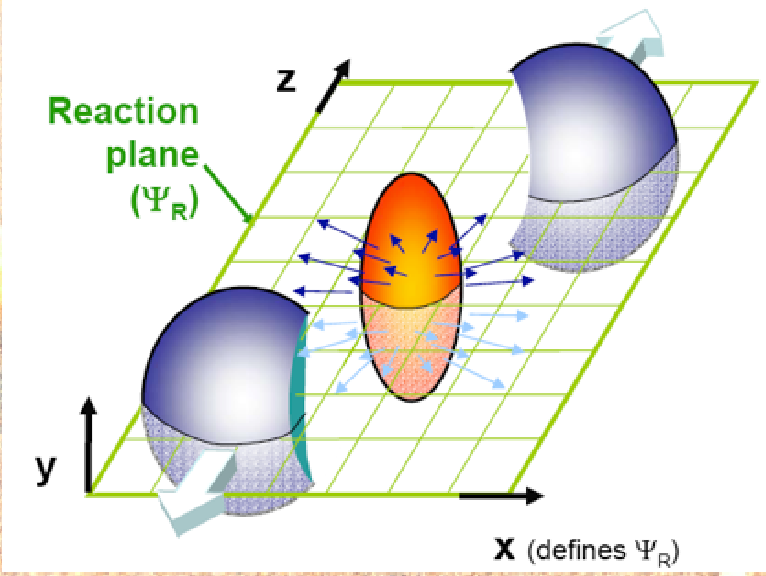
- 39 Talks + Th. + Exp. Discussion

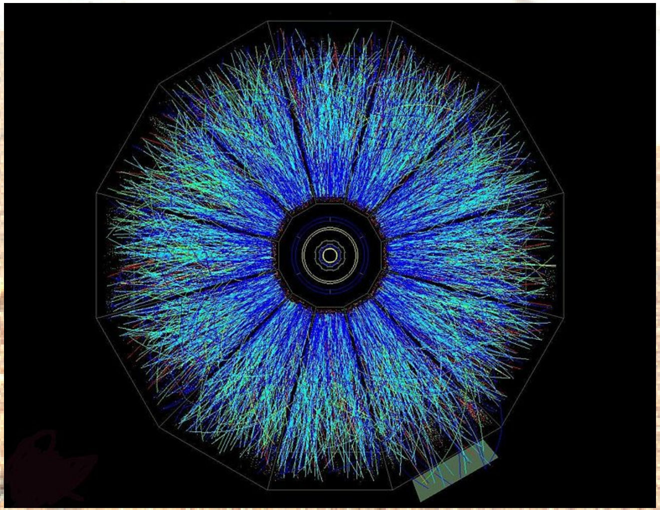
Impossible to summarize all in 15 min.
Focus on relevance to glasma + experimental results.
I am very sorry if I do not talk about your results.
Talks online: http://quark.phy.bnl.gov/~kharzeev/cpodd

- It's a personal summary

Not necessarily the viewpoint of any workshop participant,
or any other workshop organizer.

What was part of the workshop about?





P- and CP-odd effects might occur in hot matter

How to observe these effects in data?

Theoretical Results

QCD: Topological charge fluctations

Different scenarios for generating topological charge fluctuations

- Quantum tunneling: Instanton, Caloron (finite T. instanton)

  Talks by Edvard Shuryak and Pierre van Baal

- Thermal activation: Sphaleron

  Talks by Guy Moore, Valery Rubakov and Edvard Shuryak

- In Glasma

  Talk by Larry McLerran

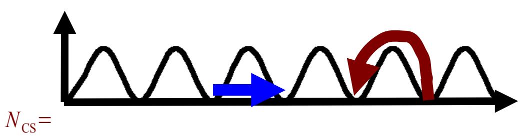
Topological charge + axial anomaly ->
chirality = P- and CP-odd effect

Big question: How much chirality is generated in a heavy ion collision??

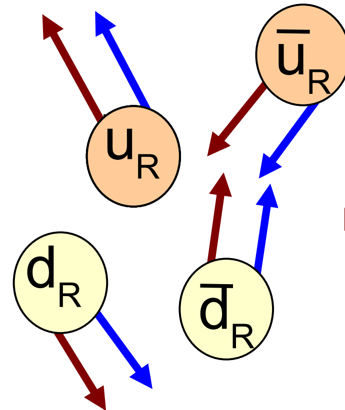
A possible way: The Chiral Magnetic Effect

Talk by Harmen Warringa

Fluctuations of top. charge

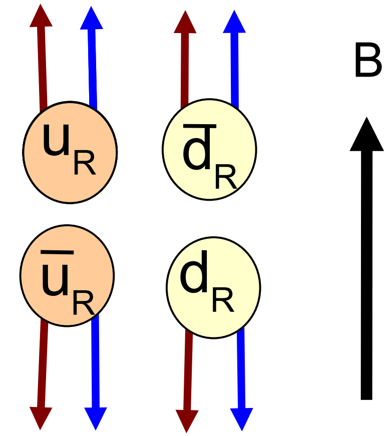


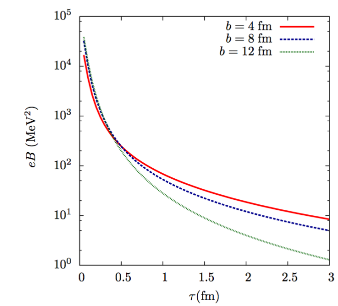
$$\langle Q^2 \rangle \neq 0$$



$$\langle N_5^2 \rangle \neq 0$$

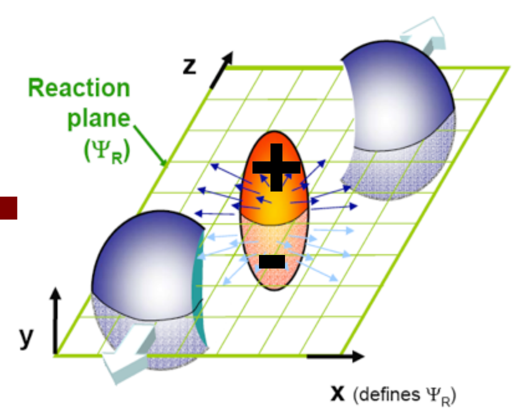
Axial anomaly: chirality
if quark mass = 0
chiral sym. restoration

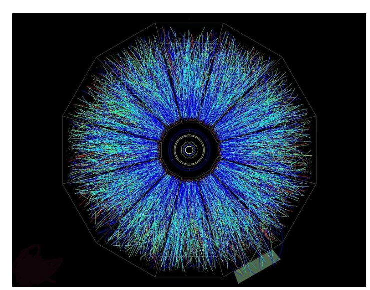




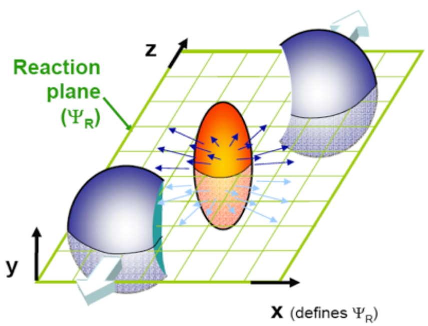
$$\langle J_z^2 \rangle > \langle J_{x,y}^2 \rangle$$

Strong EM
mag field HIC,
rapid fall-off





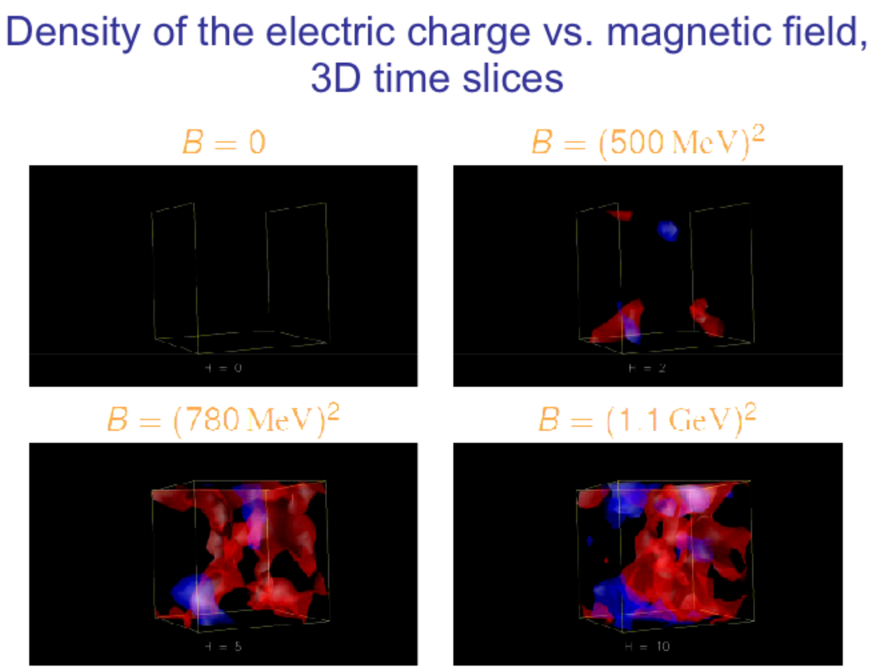
Fluctuating charge asymmetry wrt. reaction plane



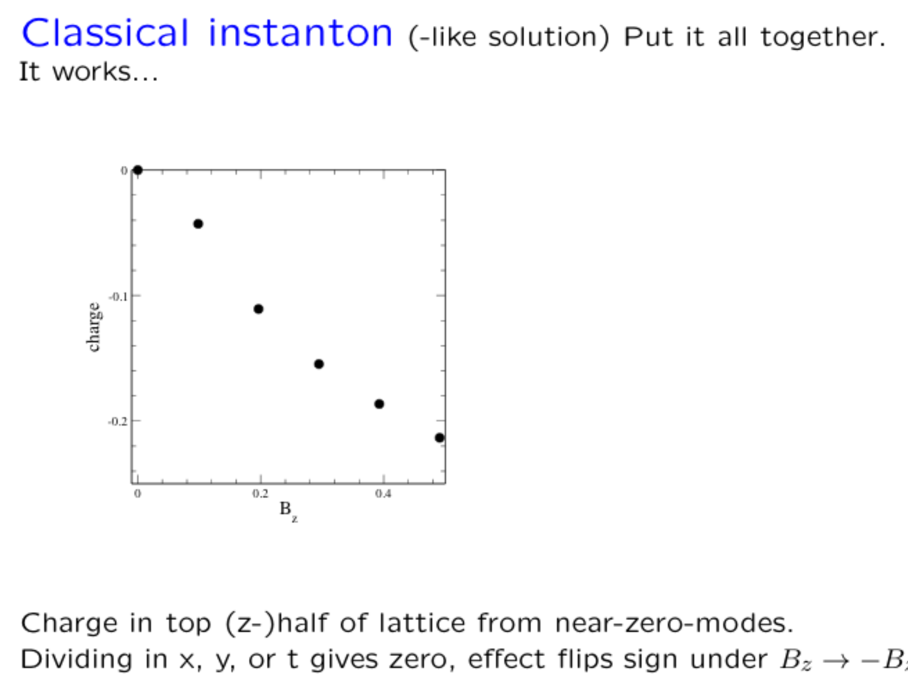
P- and CP-odd effects
in hot matter

Charge asymmetry from topology + magnetic field seems very natural

Confirmation from Lattice QCD



Talk by Mikhail Polikarpov



Talk by Tom Blum

Charge asymmetry from topology + magnetic field seems very natural

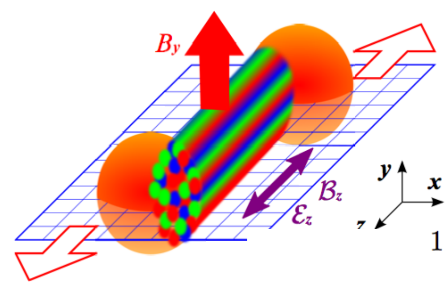
Confirmation from analytic studies

- Large axial chemical potential μ_5 for some reason
- Leads to a vector current: charge separation
- π^+ and π^- would have anticorrelation in momenta
- Some experimental signal?
- Can be explained by j~ μ_5B Kharzeev, Fukushima, Warringa, McLerran...
- Chiral rotation effect: j~ $\mu_5\omega$

Vorticity in hydro

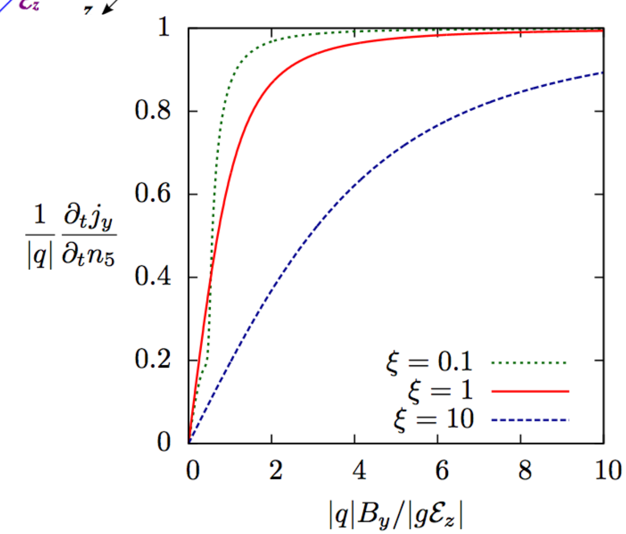
Talk by Dam Son

Problems with boundary terms in AdS/CFT
Talks by Ho-Ung Yee and Anton Rebhan



Homogeneous color flux tube + perpendicular EM mag. field

Induced current over chirality vs. mag field



Talk by Harmen Warringa

- spiral condensates arise naturally in 1+1 dim chiral models (NJL, 't Hooft, quarkyonic, ...) at finite μ
- strong B field generates dimensional reduction to 1+1
- generates charge separation along B field ("CME")
- transverse components of currents form chiral spirals ("chiral magnetic spiral")

Talk by Gerald Dunne

But there are alternatives

Talk by B. Mueller

Charge separation mech's (I)

- *CGC mechanism*: Two gluons from the initial nuclei fuse in the pseudo-scalar channel and generate an anomalous current during the peak phase of the magnetic field;
- *Glasma mechanism*: Gluons in the "glasma" generate an anomalous current in the strong magnetic field via a winding number fluctuation;
- *QGP mechanism*: Gluons in the equilibrated quark-gluon plasma generate an anomalous current in the strong magnetic field via a winding number fluctuation ("sphaleron");
- *Corona mechanism*: A neutral pion in the hadronic corona generates an anomalous current by converting into a rho-meson in the strong magnetic field;
- *Hadronic gas mechanism*: A neutral pion in the final hadronic gas phase generates an anomalous current by converting into a rho-meson in the strong magnetic field.

All have magnetic field.

Effect magnetic field on other observables. Lorentz force. *Talk by A. Chikanian*

+ others.... Initial state fluctuations + hydro evolution: *Talk by Hannah Petersen*

Quantify them all to find out which one dominates
and can describe and explain all experimental data consistently.

Experimental Results

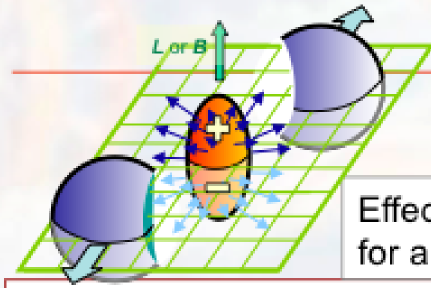
Experimental Results

Investigation of fluctuating charge asymmetries wrt. reaction plane

Observable

S.A. Voloshin, Phys. Rev. C 70 (2004) 057901

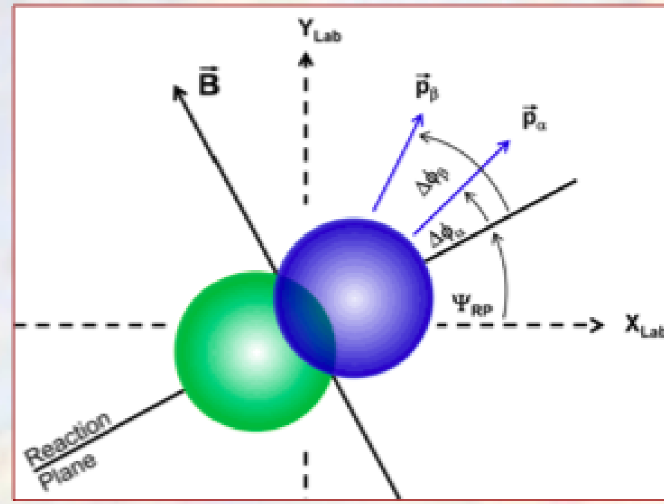
STAR



Effective particle distribution for a certain Q.

$$\frac{dN_\alpha}{d\phi} \propto 1 + 2v_{1,\alpha}\cos(\Delta\phi) + 2\,v_{2,\alpha}\cos(2\Delta\phi) + \ldots + 2a_{1,\alpha}\sin(\Delta\phi) + 2\,a_{2,\alpha}\sin(2\Delta\phi) + \ldots,$$

$$\Delta\phi = (\phi - \Psi_{RP})$$



- The effect is too small to observe in a single event
- The sign of Q varies and $\langle a \rangle = 0$ (we consider only the leading, first harmonic) ➔ one has to measure correlations, $\langle a_\alpha a_\beta \rangle$, $\mathcal{P}$-even quantity (!)
- $\langle a_\alpha a_\beta \rangle$ is expected to be ~ 10^{-4}
- $\langle a_\alpha a_\beta \rangle$ can not be measured as $\langle \sin\varphi_\alpha \sin\varphi_\beta \rangle$ due to large contribution from effects not related to the orientation of the reaction plane

➔ study the difference in corr's in- and out-of-plane

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle = \\ = \langle \cos\Delta\phi_\alpha \cos\Delta\phi_\beta \rangle - \langle \sin\Delta\phi_\alpha \sin\Delta\phi_\beta \rangle \\ = [\langle v_{1,\alpha} v_{1,\beta} \rangle + B^{in}] - [\boxed{\langle a_\alpha a_\beta \rangle} + B^{out}].$$

$$B^{in} \approx B^{out}, \quad v_1 = 0$$

A practical approach: three particle correlations: $\langle \cos(\phi_a + \phi_\beta - 2\phi_c) \rangle = \langle \cos(\phi_a + \phi_\beta - 2\Psi_{RP}) \rangle\, v_{2,c}$

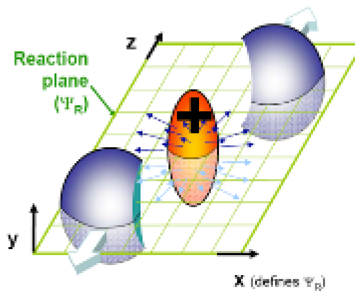
Talk by Sergei Voloshin

Charge correlations STAR

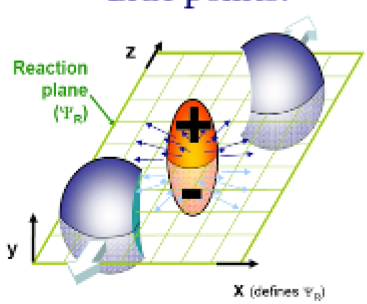
Also data at 62 GeV

min. bias, $|\eta|<1.0$, $0.15<p_t<2\,\mathrm{GeV}/c$

Red points:

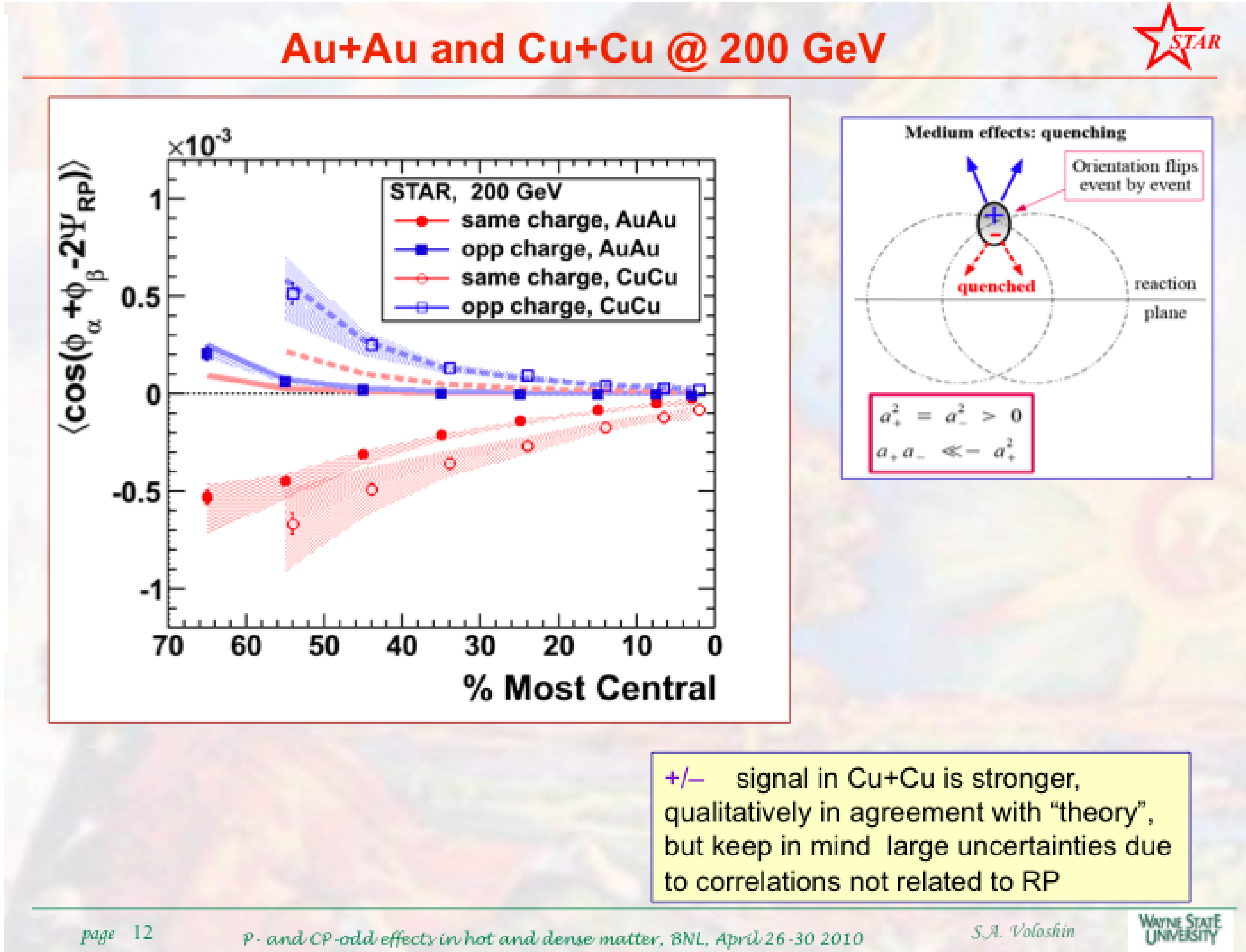


Blue points:



Data cannot be explained by

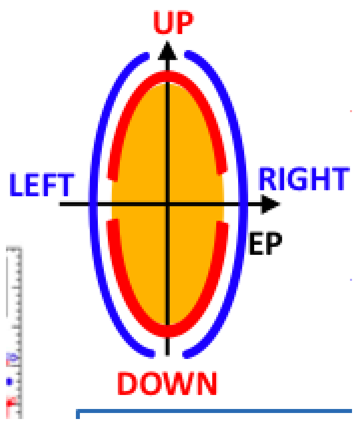
HIJING
HIJING+v2,
MeVSIM,
UrQMD



Talk by Sergei Voloshin

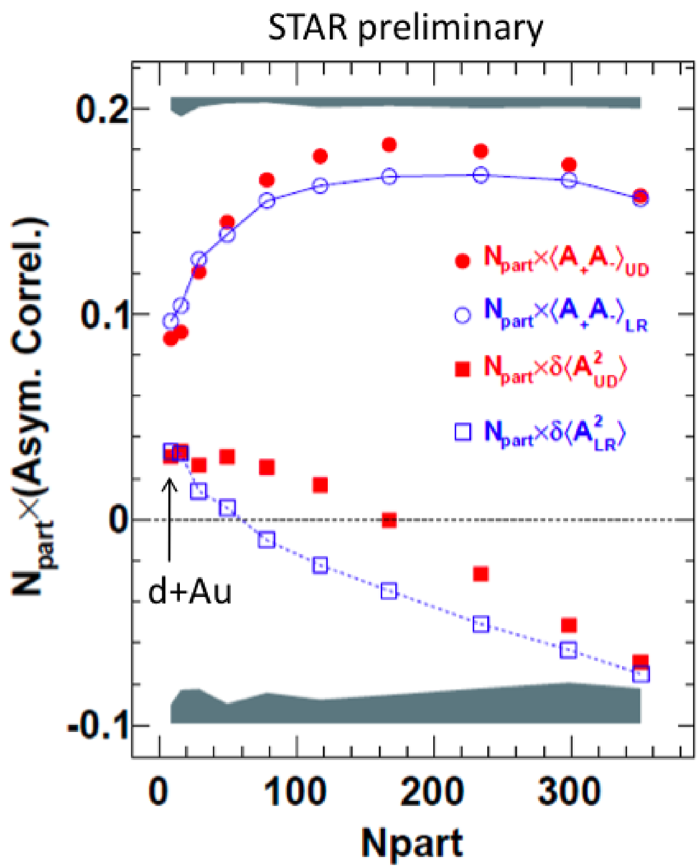
Charge correlations STAR

Charge Asym. Correl. Results

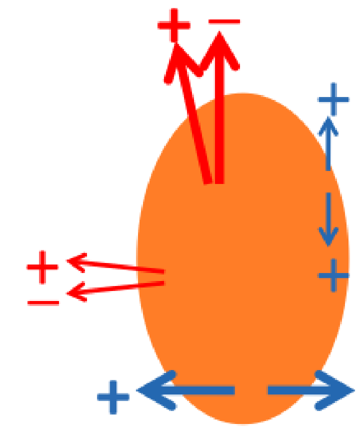


$$A_{\pm,UD} = \frac{N_{\pm,up} - N_{\pm,down}}{N_{\pm,up} + N_{\pm,down}}$$

$$A_{\pm,LR} = \frac{N_{\pm,left} - N_{\pm,right}}{N_{\pm,left} + N_{\pm,right}}$$



- Oppo-sign aligned; $\langle A_+A_-\rangle_{UD} > \langle A_+A_-\rangle_{LR}$
  LPV expects: $\langle A_+A_-\rangle_{UD} < \langle A_+A_-\rangle_{LR}$
  Contradicts LPV expectations.



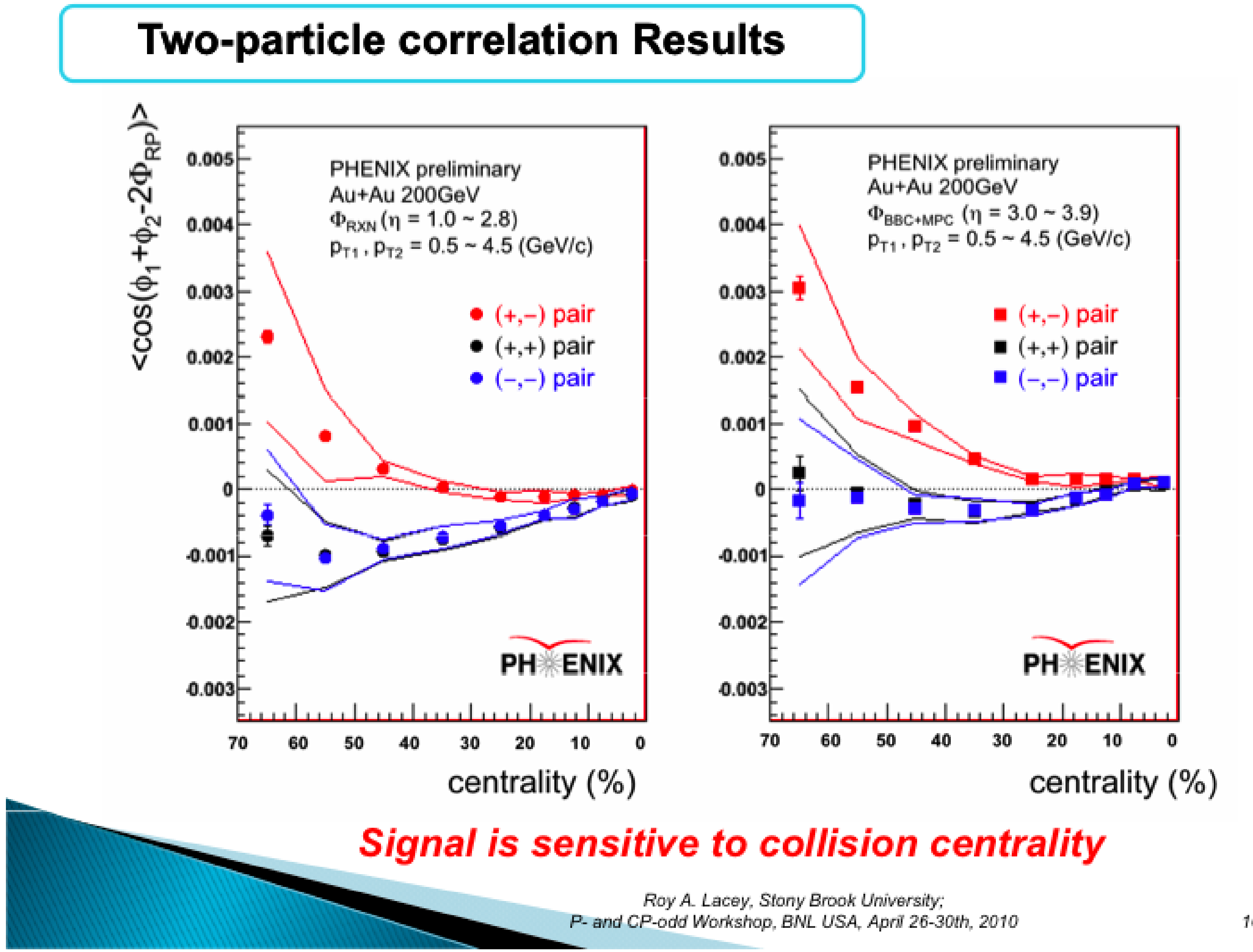
- Same-sign back-to-back in central, unexpected from *only* LPV.
  Data: $\langle A^2\rangle_{UD} > \langle A^2\rangle_{LR}$
  LPV expects: $\langle A^2\rangle_{UD} > \langle A^2\rangle_{LR}$

4/29/2010 P- and CP-odd Effects in Hot and Dense Matter -- Fuqiang Wang 7

Talk by Fuqiang Wang

Different observable gives different conclusion? Need to understand this.

Charge correlations PHENIX

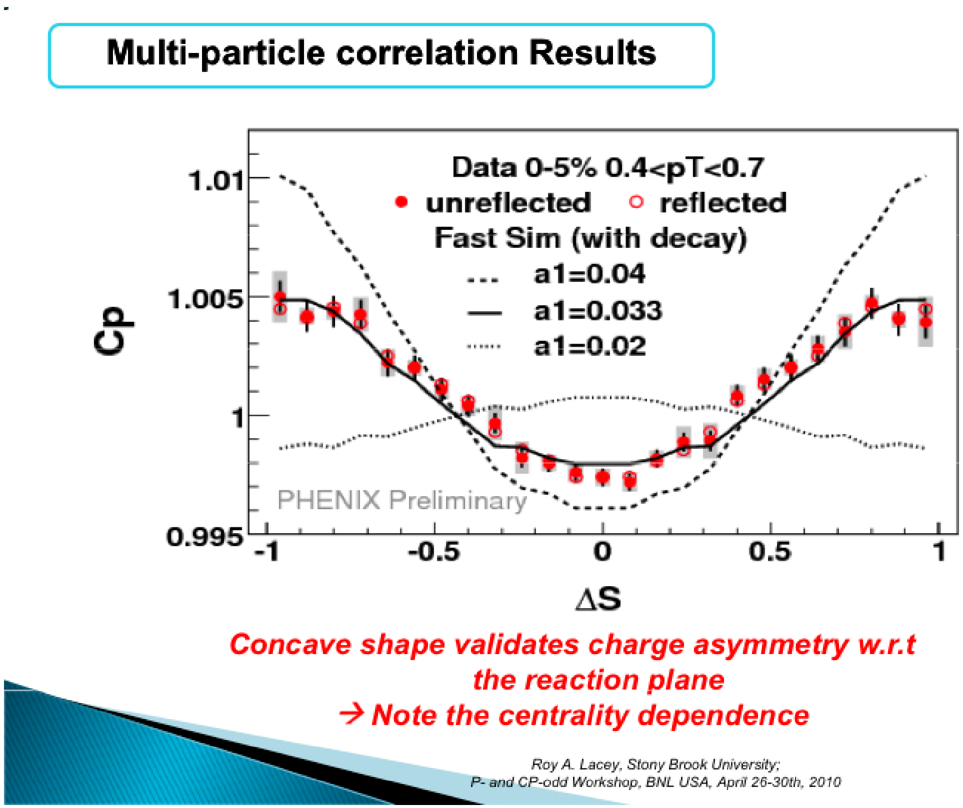


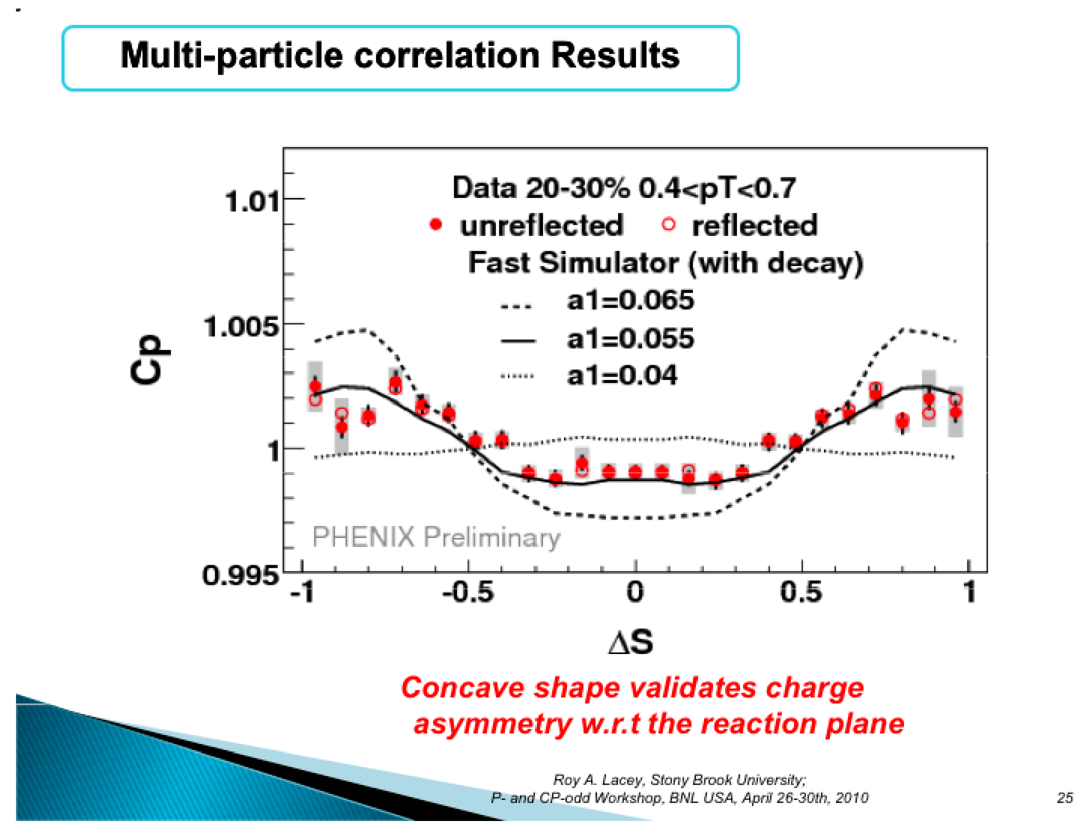
Talks by Roy Lacey

Consistent with STAR data

Charge correlations PHENIX

C_p *insensitive to flow and jets*





Talks by Roy Lacey

Another independent probe

Crucial to understand backgrounds

Background Dilemma

The "background" argument as per STAR papers

$$< \sin[\phi_\alpha - \Psi_{RP}] * \sin[\phi_\beta - \Psi_{RP}] > = B_{out} + P$$

$$< \cos[\phi_\alpha - \Psi_{RP}] * \cos[\phi_\beta - \Psi_{RP}] > = B_{in}$$

$$B_{in} = B_{out} \;?$$

What data do show: $B_{out} \approx -P$

Call for critical and detailed investigation:

- what is in the background?
- fine-tuning cancellation? What? Why?
- Pt & eta differential study of projected correlations
- Projected correlations in CuCu
- **Other observables?**

NEED BOTH !

$\cos[\phi_\alpha + \phi_\beta]$

$\cos[\phi_\alpha - \phi_\beta]$

Talk by Jinfeng Liao

Also need to understand relation between different observables
Discussion session by Paul Sorensen

My personal conclusions

- Topological charge fluctuations in the presence of external magnetic field lead to P- and CP-odd effects which cause electric charge fluctuations perpendicular to reaction plane. The magnitude is however uncertain.

- The magnetic field is only large at initial time, if the above mechanism is realized the glasma is key to its understanding.

- There are also alternative mechanisms for charge fluctuations. Need to quantify them all and come with detailed predictions, e.g. dependence on energy, species, impact parameter, rapidity, particle ID, etc.

- Both STAR and PHENIX have observed charge correlations in azimuthal angle. Evidence for fluctuating charge asymmetries. Need to understand backgrounds and make all observations consistent.

- In order to explain the source of the observed asymmetries, detailed quantitative predictions from theory are required, with help of additional results from experiment.

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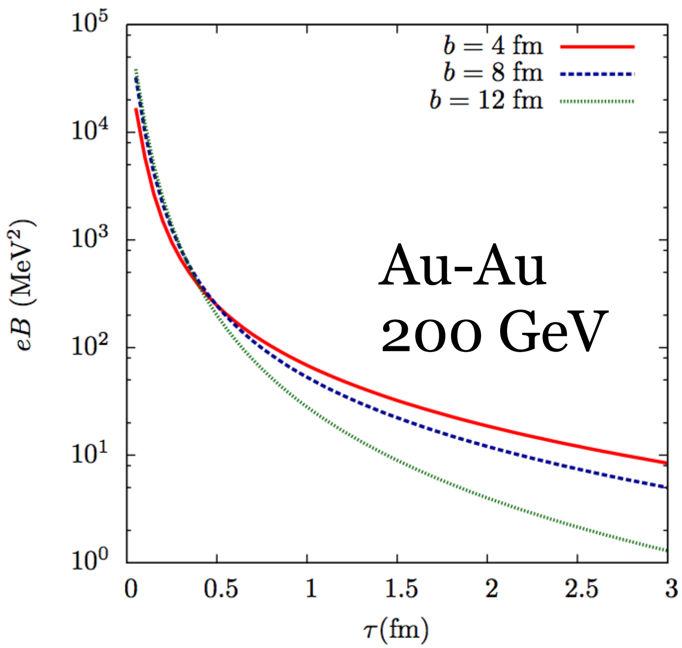
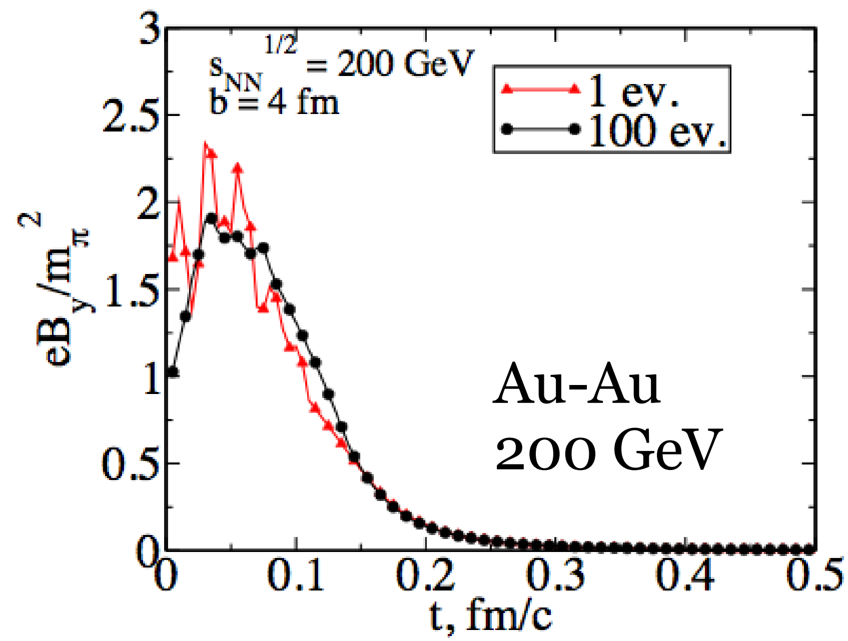
Backup slides

Ultra high-energy heavy ion collisions = Ultra strong (EM) magnetic fields



Pancake approximation
Kharzeev, McLerran & HJW ('08)
See also Minakata and Müller ('96)



URQMD calculation
Skokov, Illarionov, Toneev ('09)

$$eB(\tau = 0.2\ \mathrm{fm/c}) \approx 10^3 \sim 10^4\,\mathrm{MeV}^2 \approx 10^{18}\,\mathrm{G}$$

Talks by A. Chikanian, Jorn Boomsma, Eduardo Fraga, ...